Table 2--of Hazardous Interference by Orbital Debris

1. Loss or damage to space assets through collision;
2. Accidental re-entry of space hardware;
3. Contamination by nuclear material of manned or unmanned spacecraft, both in space and on Earth;
4. Interference with astronomical observations, both from the ground and in space;
5. Interference with scientific and military experiments in space;
6. Potential military use.

SOURCE: Space Debris, European Space Agency, and Office of Technology Assessment.

Earth. The largest have attracted worldwide attention.[10] Although the risk to individuals is extremely small, the probability of striking populated areas still finite.[11] For example: 1) the U.S.S.R. Kosmos 954, which contained a nuclear power source,[12] reentered the atmosphere over northwest Canada in 1978, scattering debris over an area the size of Austria; 2) a Japanese ship was hit in 1969 by pieces of space debris that were assumed to be of Soviet origin, injuring five sailors; 3) in October of 1987, a 7-foot strip of metal from a Soviet rocket landed in Lakeport, California, causing no damage; 4) portions of Skylab came down over Australia in 1979. The biggest piece of Skylab that reached the ground weighed over 1,000 pounds.[13]

This background paper treats the issue of artificial debris in space, its causes, and the potential for reducing the hazards that it poses to space activities and the outer space environment. Yet, orbital debris is part of a larger problem of pollution in space that includes radio-frequency interference and interference to scientific observations in all parts of the spectrum. For example, emissions at radio frequencies often interfere with radio astronomy observations. For several years, gamma-ray astronomy data have been corrupted by Soviet intelligence satellites that are powered by unshielded nuclear reactors.[14] The indirect emissions from these satellites spread along the Earth's magnetic field and are virtually impossible for other satellites to escape. The Japanese Ginga satellite, launched in 1987 to study gamma-ray bursters, has been triggered so often by the Soviet reactors that over 40 percent of its available observing time has been spent transmitting unintelligible "data."[15] All of these problem areas will require attention and positive steps to guarantee access to space by all countries in the future.

FINDINGS

Finding 1: If space users fail to act soon to reduce their contribution to debris in space, orbital debris could severely restrict the use of some orbits within a decade or two.

Orbital debris is a growing problem. Continuing steady growth of orbital debris could, by 2000 or 2010, render some well-used low-Earth orbits (LEOs) too risky to use.

[10] Salyut 7, the mothballed Soviet space station, which had beenorbitingin a storage orbit of some 300 kilometers, has slowly slipped to lower altitudes as a result of increased solar activity and is expect to fall to Earth in April 1991. It will be the largest object to reenter Earth's atmosphere since Skylab. Lon Rains, S'News, vol. 1, No. 8, p. 1.

[11] Early in the U.S. space program, rocket launches dropped debris over portions of Africa, which caused considerable concern to U.S. officials. See K H. Meyer and H. H. Hunt, "Investigation of Atlas Booster Fragments Recovered in South Africa," December 1963 (NASA contract NASw-537), General Dynamics Astronautics, San Diego, CA.

[12] See Eilene Galloway, "Nuclear Powered Satellites: The U.S.S.R. Cosmos 954 and the Canadian Claim," *Akron Law Review*, vol. 12, *No.* 3, pp. 401-415, for a comprehensive summary of the legal and political ramifications of this incident.

[13] R. Reinhold, "Space Junk Emits Clatter From Coast to Coast," New *York Times, Oct.* 14, 1987.

[14] M. Waldrop, "Space Reactors Hinder Gamma-Ray Astronomy," Science, vol. 242, November 1988, p. 119. The U.S. Solar Max spacecraft picked up bursts of gamma rays lasting anywhere from a few seconds to almost 2 minutes. The reactors provide power for the Soviet military's Radar Ocean Reconaisssance Satellites (RORSATs), which are used to track Weetern fleet movements, and which have been launched at the rate of two or three per year since the 1980s.

[15] Ibid.

Other orbits, including the economically and strategically important geostationary orbital band (GEO), are vulnerable to the growth of debris. Debris can collide with both active and inactive satellites, damaging the active satellites and producing more debris from both. Pollution in the form of gases and small particles of rocket exhaust may erode and contaminate spacecraft surfaces. Debris may also interfere with inspace and ground-based observations and experiments. International action will be needed to minimize the generation of new orbital debris and to cope with debris already in orbit. The United States and other countries have already taken initial steps to reduce their contributions to orbital debris. Future planning needs to consider the potential long-term effects (50 years and longer) of space debris.

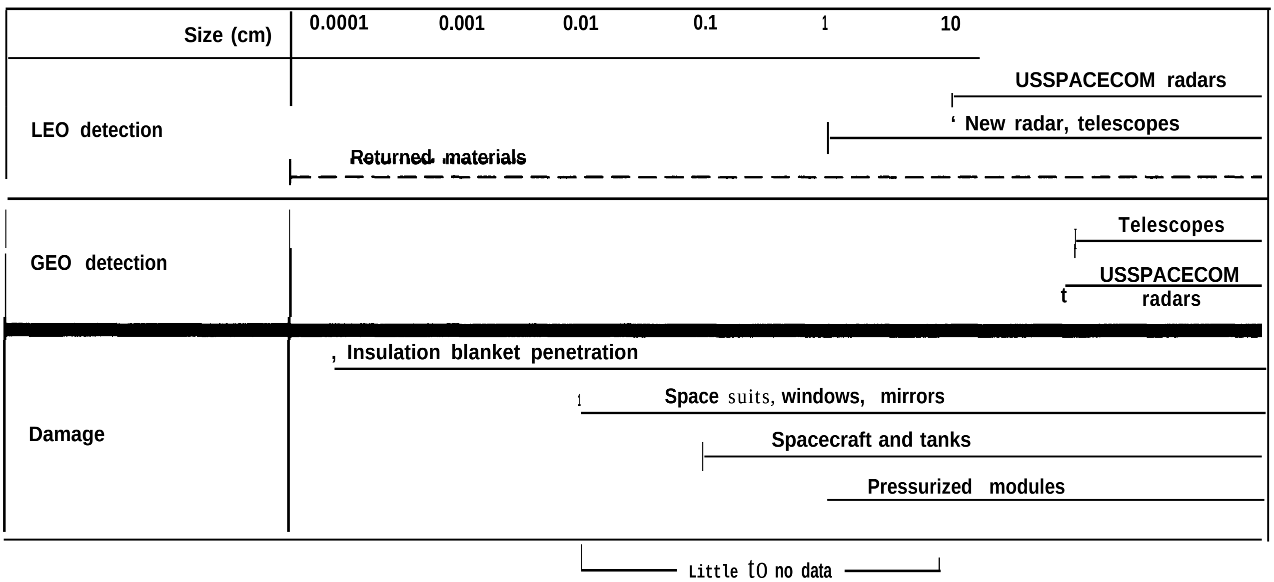
Three critical areas require particular attention:

- developing cost-effective strategies to reduce the contributions to orbital debris;
- encouraging immediate action to minimize debris production by all space-faring nations and organizations; and
- increasing the awareness and involvement of the international community.

Finding 2: Lack of adequate data on the orbital distribution and size of debris will continue to hamper efforts to reduce the threat that debris poses to spacecraft.

The distribution of orbital debris is determined by a variety of means (figure 2), including the use of radar, optical telescopes, and direct observations of damage to items returned from space. Although the Space Surveillance Network (SSN), operated by the U.S. Space Command, currently tracks about 6,500 orbital objects 10 centimeters across and larger (6 percent of which are active spacecraft), smaller debris cannot be followed with current systems. **The nature and extent of the hazard from smaller particles is therefore highly uncertain.** Some analysts estimate

Figure 2-Orbital Debris Relationships



SOURCE: National Aeronautics and Space Administration that some 30,000 to 70,000 bits of debris, one centimeter or greater in diameter, now orbit the Earth. Many more smaller objects are estimated to be in orbit.[16] Other analysts are skeptical of such projections. However, all agree that neither the number nor the distribution of these objects is sufficiently well known to predict which methods of protection would be most cost-effective.

Reducing these uncertainties to acceptable levels will require the development of devices capable of sensing and cataloging smaller objects, and sampling debris in orbit. The Haystack Auxillary Radar, under development by NASA and the Department of Defense (DOD) (operated by USSPACECOM), together with data from the existing Haystack Radar, will assist in characterizing the number and distribution of objects as small as 1 centimeter in diameter. The information supplied by examining the Long Duration Exposure Facility (LDEF),[17] which remained in LEO nearly 6 years, will help in estimating the debris density in LDEF's orbits and in evaluating the long-term effects of the space environment on a wide variety of materials used in spacecraft. Similar future experiments in orbit would continue to assist the accumulation of information on microscopic orbital debris.

To define the space environment adequately, more and better data must also be acquired in the laboratory on the types of explosions that can occur in space and on the effects of impacts, especially hypervelocity impacts (relative velocities of 3 kilometers per second and greater). Impacts occuring at velocities of 5 to 7 kilometers per second and greater lead to great damage because they can cause the impacting materials to liquify and produce many thousands of small particles. The remainder of a satellite may also fragment into hundreds of large pieces capable of causing catastrophic damage to other satellites. However, the details of these mechanisms are not completely understood.

Better orbital debris information will contribute to the development of more accurate predictive models for the evolution of space debris. These data will also support efforts to develop debris reduction and spacecraft protection techniques.

Finding 3: The development of additional debris mitigation techniques could sharply reduce the growth of orbital debris.

A number of relatively simple preventive measures taken by national governments and space organizations would greatly reduce the production of orbital debris. Government-funded research has shown that it is possible to design and operate launch vehicles and spacecraft so they have minimum potential for exploding or breaking up. For example, since 1981 NASA has depleted propellants and pressurants from Delta launch vehicle upper stages after they have completed their mission. NASA has also added electrical protection circuits to spacecraft batteries in order to preclude battery explosions resulting from electrical shorts. Spent upper stages can be removed passively by reducing their altitude to the point where atmospheric drag effects will bring them down. The U.S. Government may implement this technique in the future. Although these and other techniques add a few kilograms to the weight of the spacecraft and the launch vehicle, and therefore increase the cost of a mission, such extra costs maybe necessary to avoid potentially greater costs from failed missions later. In other words, they may well be cost-effective in the long-run.

Further, the use of new materials on spacecraft could reduce the natural degradation

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[16] Information regard objects smaller than 0.10 centimeters can only be obtained from materials returned from space. Although these objects might number as much as 3,500,000, objects of this size are not considered a great threat.

[17] See box 5 for findings from LDEF.

and fragmentation that occurs in the harsh environment of outer space. Moreover, nations could avoid deliberately fragmenting satellites. Finally, some experiments can be planned for execution in very low orbit, where the atmospheric drag will bring objects down relatively quickly.[18]

Finding 4: Although it is technically feasible to remove existing debris from low altitudes, the cost of removal is not warranted at this time.

Proposals for debris removal have ranged from developing large balloon-like objects that would "sweep up" debris in certain orbits, to using the Space Shuttle and/or the planned Orbital Maneuvering Vehicle (OMV) to capture inactive satellites and remove them from orbit.

All methods for removing debris exact some economic cost. However, for LEO, the least expensive technique is to remove inactive payloads and spent propulsion stages before they can break up into smaller objects. Removal involves reserving some fuel to send spent propulsion stages or inactive satellites into the atmosphere, where they will break up and bum or fall to Earth.[19] Adding a small device directly to a propulsion stage that would later expand and increase atmospheric drag would also substantially shorten the stage's lifetime on orbit.

The capture and return of space objects is expensive.[20] The present degree of risk does not make debris worthwhile to remove from space. In addition, the potential salvage value of a used satellite, unlike that of an abandoned ship, is extremely small compared to the cost of retrieval at present. Further, unless the launching state were to agree, it is contrary to current international law[21] to interfere with space objects belonging to another state or states. Even inactive satellites, which could threaten the operation of other satellites, remain the property of the states of registry and continue under their jurisdiction. No concomitant duty to dispose safely of inactive satellites exists, and no liability accrues if they substantially interfere with active satellites, though activities generating inactive satellites may be made the subject of consultation pursuant to Article IX of the 1967 Outer Space Treaty.[22]

Finding 5: Protection technologies could reduce the harm that debris can do.

Orbital debris ranges from submillimeter-sized particles to objects several meters long. Although the chances that one of the few large pieces of debris would strike a functioning spacecraft is extremely small, the probability that collisions with objects in the millimeter to centimeter size range would reduce spacecraft performance is growing.

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[18] For example, the Delta 180 experiment for the Strategic Defense Initiative Organization was carried out in low orbit, in compliance with DOD policy on space debris (Department of Defense Space Policy, Mar. 10, 1987).

[19] The U.S. Government is actively considering followingthis practice. Full implementation will require further effort to design the procedures for each specific application.

[20] The recent return of LDEF and its many experiments to Earth demonstrates that such retrieval is possible. However, LDEF was retrieved to recover its valuable experimental results, not for its salvage value, or because it might harm active spacecraft. NASA will charge Intelsat more than $90 million to capture and repair an Intelsat VI communications satellite now stuck in a useless low orbit. James R. Asher, "Astronauts to Catch Stranded Intelsat for $90 Million for Reboost in 1992," *Aviation Week and Space Technology*, June 18, 1990, pp. 26-26.

[21] Article VIII of the *1967 Treaty on Principles Governing Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*: "A State Party to the Treaty . . . shall retain jurisdiction and control over such object . . . while in outer space . . . ."

[22] Article IX states: "A State Party to the Treaty which has reason to believe that an activity or experiment planned by mother state Partyin outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with activities in the peaceful exploration and use of outer space, including the Moon and other celestial bodies, may request consultation concerning the activity or experiment. "

Efforts to develop protection technologies and methods include materials research, active and passive avoidance techniques, and new shielding designs. Current shield designs make use of an outer wall that causes the striking object to fragment and disperse before hitting the inner wall. A specific dual-wall design is effective for all debris velocities *in excess* of about 5 kilometers per second and particle size of about 0.5 centimeter. Additional research and development will be needed to design more effective, lightweight shields. New materials and techniques will assist that effort. However, some shielding materials could add to the debris hazard. Hence, research on shielding will have to include study of the breakup or degradation of shielding over time.

Finding 6: The presence of debris in low-Earth orbits, where fast moving objects could pierce inhabited spacecraft such as the planned international space station, *Freedom*, and the Soviet space station, *Mir*, is especially troublesome because of the risk to human life.

The tiny paint chip that damaged the Shuttle *Challenger's* windshield in 1983 is evidence of a large population of very small particles. The paint chip would likely have punctured the spacesuit of an astronaut involved in extravehicular activity, had it struck him, though the probability of such an impact is extremely small.[23] Operation of the Space Shuttle could be endangered by orbital debris, especially as Shuttle flights increase in length.[24]

Objects quite a bit larger than the paint chip could pierce the Shuttle and/or space Station *Freedom.* Soviet cosmonauts aboard *Mir* have noted some impacts from small pieces of artificial debris.[25] Although these encounters have not resulted in life-threatening damage, they illustrate the potential threat. Additional data from *Mir* regarding Soviet experience with orbital debris could be very useful in designing appropriate shielding for *Freedom*.

Space station designers will need additional data in order to design effective shielding for *Freedom,* particularly for debris less than 2 centimeters in diameter.[26] The final design requirements for the space station are needed by 1992 in order for them to be incorporated in the hardware. NASA has recently revised its estimates of the debris hazard,[27] which new data shows may have been understated,[28] and continues to refine its understanding of the space environment. Study of the actual experience of debris encounters with LDEF and observations by the Haystack Auxillary Radar, under development by NASA and the Air Force, will play important roles in providing the necessary data.

Freedom will also require tight environmental control to limit generation of orbital debris. Space stations, especially because they are large and have a large surface area also have the potential to produce debris. Over several years, as debris generated by the space station changes orbit slightly and expands into a doughnut-shaped belt, space stations themselves, as well as launch vehicles supplying them, would become targets of space station debris.

[23] L. Parker Temple III, "The Impact of Space Debris on Manned Space Operations" (IAA-86-420), presented at the 37th Congress of the International Astronautical Federation, Innsbruck, Austria, Oct. 4-11, 1988.

[24] U.S. Congress, General Accounting Office, "Space Debris a Potential Threat to Space Station and Shuttle," GAO-CC-90-18 (Washington, DC: GeneraI Accounting Office, April 1990), ch. 5.

[25] William Djinis, National Aeronautics and Space Administration, personal communication, 1990.

[26] Shielding for objects greater than 2 centimeters in diameter would be impractically massive. Fortunately, the risk to the Space Station of encountering objects larger than 2 centimeters is much lower than for the smaller ones.

[27] R. Nieder, "Implication of Orbital Debris for Space Station Design" (AIAA 901331). AIM/NASA/DOD Orbital Debris Conference: Technical Issues and Future Directions, Apr. 1619, 1990, Baltimore, MD.

[28] U.S. Congress, General Accounting Office, op. cit., footnote 24, P. 28.

Finding 7: Addressing the orbital debris problem will require the active involvement of all space-capable nations.

Outer space is by nature *and* treaty a global commons. Solving orbital debris problems will require the cooperation of countries capable of reaching orbit. The United States and the Soviet Union are the two largest contributors to the orbital debris population. As other nations increase their space activities, their contribution to the debris population will increase dramatically, unless they also take preventive measures.

The United States has assumed the lead in analyzing the orbital debris distribution and in developing mitigating technologies and methods. The 1989 report of the Interagency Group (Space)[29] has assisted in making the hazards posed by orbital debris more widely appreciated and understood.

Informal discussions among technical representatives of most of the launching nations, convened by the United States, have already proven highly beneficial in developing orbital debris control policies and practices. For example, the Japanese National Aeronautics and Space Development Agency (NASDA) and the European Space Agency (ESA) have both incorporated procedures in their launch sequences to dispense unused propellant after upper stages are used. Discussions between these agencies and NASA have also resulted in the prospect of sharing information on debris tracking, modeling, and hypervelocity testing. In November 1988, ESA released its report on space debris,[30] which reached conclusions similar to those of the later U.S. orbital debris report.

Initial discussions with Soviet officials in December 1989 have proven fruitful to representatives from NASA, who have hitherto had little insight into Soviet efforts to study the problem or to curb its contributions to the orbital debris population.[31] The United States has not yet formally discussed the problems of orbital debris with the People's Republic of China, which has a growing space program.

Finding 8: Existing international treaties and agreements are inadequate for minimizing the generation of orbital debris or controlling its effects. An international treaty or agreement specifically devoted to orbital debris maybe necessary.

One major objective of the international treaties and agreements *on* space activities is to ensure that space activities can be conducted safely, economically, and efficiently. Yet, existing international treaties and agreements do not explicitly refer to orbital debris. As a result, they leave uncertain the legal responsibilities of nations for minimizing the growth of orbital debris.

The economic value of maintaining a safe operational environment for all nations provides strong motivation for nations to take independent action. Yet nations that conduct relatively few launches might consider their contribution to orbital debris to be small. However, as the November 1986 breakup of an Ariane third stage demonstrated,[32] even one breakup can cause a large amount of debris. An international agreement on orbital debris could set the framework for tackling the hazards of orbital debris. To be effective, an international legal regime for debris

[29]National Security Council, Op. Cit., fOOtnOte 2.

[30]European Space Agency, op. cit., *footnote* 3.

[31] Djinis, op cit., footnote 25.

[32]Nicholas L. Johnson, "Preliminary Analysis of the Fragmentation of the Spot 1 Ariane Third Stage," in Joseph P. Loftus (d), *Orbital Debris From Upper-Stage Breakup,* Progress in Astronautics and Aeronautics, vol. 121, 19S9, pp. 41-106.

should address the generation of debris, its removal from orbit, and the possible remedies for damage sustained from debris. However, experience with the development of other treaties suggests that negotiating such an agreement could be arduous and time-consuming.

The United States, and some other governments, are currently reluctant to enter into negotiations over an international agreement on orbital debris, because the uncertainties about debris distribution and potential mitigation methods are still high. In addition, when addressed in a broad multilateral context in which states having no current capability to launch objects into space would participate, the subject has a high potential for becoming the subject of acrimonious debate in which the technical issues and solutions could be lost. However, eventually a formal agreement will probably be necessary in order to encourage all space-faring nations to minimize the production of orbital debris.

It maybe appropriate for the United States to convene a working group limited to space-faring nations that would discuss mitigation strategies and seek to reach agreement on them. The United States is now urging these nations, both informally and formally, to adopt as policy a statement similar to the U.S. policy on orbital debris: "all space sectors[33] will seek to minimize the creation of orbital debris. Design and operations of space tests, experiments, and systems will strive to minimize or reduce accumulation of space debris consistent with mission requirements and cost effectiveness." This follows U.S. policy, adopted in 1989, that "the United States Government will encourage other space-faring nations to adopt policies and practices aimed at debris minimization."[34]

In the long run, enlightened self-interest is likely to draw most nations with an interest in outer space into such negotiations. Many of the partners in such international organizations as Intelsat, Inmarsat, and Intersputnik, or regional entities such as ESA, Arabsat, and Eutelsat, have an economic interest in maintaining the ability to exploit space, even if they lack the ability to launch spacecraft themselves.

Finding 9: For an international legal regime on orbital debris to be established, several legal issues, including the definition of orbital debris, jurisdiction and control over orbital debris, and the treatment of liability for damage from orbital debris, need to be resolved.

Legal experts do not now agree on a definition of space debris. For example, one major point of debate is whether inactive satellites should be categorized as "debris." Without a common definition, agreements over jurisdiction and control and liability will be extremely difficult to achieve. Hence, if the United States and other nations enter into negotiations over an international agreement on orbital debris, one of the first items of business will be to reach agreement on a definition of orbital debris, and what items are included in or excluded from the category.

It will also be necessary to provide more explicit guidelines concerning the ownership of, and jurisdictional control over orbital debris. Existing legal opinion favors the view that jurisdiction and control of a State over its space objects is permanent, even if the object no longer serves a useful purpose. However, most space debris consists of objects too small to be identified. It maybe necessary for the international community to develop a set of principles regarding the treatment of spent satellites.

Under existing law, launching States cannot beheld liable for the mere presence of orbital debris in outer space. Lack of international agreements on debris is of particular con-

[33] In other words, civilian and military government programs, and the private sector.

[34] White House, President Bush's Space Policy, November 1989, Fact Sheet.

cern because launching States have no legal incentive to avoid generating orbital debris, although they have the practical, self-serving incentive of protecting their own spacecraft. An international agreement on space debris should include provisions dealing with these and other issues.

Reaching agreement will eventually require abroad international approach, supported by individual national efforts. Considerable additional research on the distribution and hazard posed by space debris will be needed to support international legal efforts. Meanwhile, nations and organizations that launch or operate spacecraft can voluntarily take immediate steps to minimize debris.

Finding 10: Private-sector space activities have already benefited from orbital debris research carried out by governments. As private space activities increase, firms will have to bear their share of the burden of mitigating future contributions to the orbital debris population.

The private sector has a major stake in reducing space debris, because an increased debris population could harm private activities. As noted in Findings 3, 4, and 5, Federal investment in debris research has resulted in greater knowledge of the potential harm of space debris and in a variety of measures to mitigate its threat to space operations.

U.S. private-sector space activities are regulated by the U.S. Government in accordance with several U.S. laws. In particular, *The Commercial Space Launch Act of 1984*[35] mandates that all commercial payloads must be reviewed prior to being licensed for launch. The Act gives the Office of Commercial Space Transportation (OCST) in the Department of Transportation the responsibility for licensing commercial launches. This licensing process includes a review of intended safeguards against proliferation of space debris.

Although some safeguards will require additional costs for payload owners and providers of launch services, the Federal Government does not wish to prejudice unnecessarily the international competitiveness of the U.S. launch industry.[36] Hence, to avoid overburdening the private sector, regulation will have to be measured and in concert with reducing the threat of space debris while maintaining U.S. competitiveness with other nations.

Private-sector input to the process of minimizing space debris generation will be extremely important in ensuring that regulations take into account the concerns and needs of private fins, consistent with providing appropriate protection to spacecraft and people in space. Private firms could be especially helpful in comparing the costs of instituting certain debris reduction procedures with the costs of losing spacecraft capability as a result of debris impacts.

Finding 11. Many misconceptions about orbital debris exist. An international educational program about orbital debris would assist in making the hazards of space debris better understood.

Even individuals knowledgeable in other areas of space activities have developed misconceptions about the distribution of space debris and potential hazards (box 2). Continued research and promulgation of results will be needed to improve knowledge of this critical area. The many research reports written by officials at NASA, the Air Force, and industry have alerted the space community to the hazards of space debris. These have been presented over the years at national and international technical symposia sponsored by organizations such as the American Institute for Aeronautics, the American Astronautical Society, the International Astronautical Federation, and the Committee on Space Research. The recent reports by the U.S. Interagency Group (Space) and ESA have reached an even

3549 U.S.C. 2601-2623 (19S4 & supp. 1987).

36National Security Council, op. cit., fOOtnOte 2, pp. 49-50.

Box 2-Nine *Common Misconceptions About Orbital Debris*

One of the major impediments to reducing orbital debris is the lack of knowledge and understanding of the problem. The following paragraphs explore some of the most common misunderstandings about orbital debris.

Misconception 1. Space debris is a larger problem today because the international space launch rate has increased.

On the contrary, **the cataloged debris population has steadily grown while the international launch rate has remained stable.**

Since 1965 the international space launch rate has averaged 117 a year, never dipping below 100,yet the cataloged population has increased sixfold (figure 3 and figure 4) in the same period. There is no clear dependency between the launch rate and catalog growth. Catalogd space objects have increased at an average linear rate of 240 objects per year (including active payloads and debris).

Misconception 2. The hazard from orbital debris is well defined.

***On the contrary,* there is significant uncertainty (orders of magnitude) in the probability of collisions and the effect of the impact of debris.**

The hazard to a functioning satellite is determinedby the probability of collision and the lethality of impact. Because the number of debris objects in various orbits is uncertain, the probability of collision calculated from the density and velocities of cataloged objects (app. A) is also uncertain. Hence, estimates of future hazard reflect, or should reflect, that uncertainty. Because the number of small objects in each orbital regime is thought to be much greater than those that can be tracked by the SSN, the hazard is likely to be much greater than that estimated from cataloged data.

The actual effects of collision on an active spacecraft are also uncertain. A collision might destroy an active spacecraft or it might only damage part of it. For example, although a 100 gram debris fragment traveling at 10 kilometers per second (the average relative velocity in LEO) possesses the destructive energy of one kilogram of TNT, it may strike the satellite in an area that would damage, but not destroy, the satellite.

In addition, the nature of the debris environment is very dynamic; both the sources and sinks of debris will change over time, adding to the difficulties of defining the debris environment.

Misconception 3. The cessation of satellite breakups will solve the orbital debris problem.

On the contrary, **the hazard from debris already residing in space, coupled with other sources of new debris, such as debris resulting from space operations, will still create a concern for many years to come even if no more satellites were to fragment in the future.**

About 45 percent of the cataloged population is the result of nearly 100 satellite fragmentations (figure 1).[1] Elimination of spacecraft explosions is more effective than any other method of controlling space debris growth. Yet, there are still other significant sources that must be controlled. The remnants of successful space missions, spent rocket bodies, and inactive payloads account for one third of the catalog. These objects are large and maybe the source of future debris. Satellite deterioration as the result of reaction with atomic oxygen and thermal cycling could produce fragments that range in size from micron-size paint chips to large solar panels. These payloads and rocket bodies may also remain in orbit a longer time than fragmentation debris.

The last category, operational debris, makes up 12 percent of the trackable objects in orbit.[2] This debris is released during normal operations of satellites: lens covers, explosive bolts, springs, shrouds, spin-up mechanisms, empty propellant tanks, etc. Crews have even accidently released items during extravehicular activities and been unable to retrieve them. However, at altitudes in which the Shuttle operates, objects reenter relatively frequently.

Misconception 4. International laws and treaties help to control the growth of the orbital debris population.

***On the contrary,* no formal laws or treaties have any impact on the control of orbital debris.**

There is at present no international law or treaty that specifically calls for the control, reduction, or elimination of "space debris." Some feel that an international legal agreement formulated now may unnecessarily restrict future space operations. Yet, if the spacefaring nations do not act soon on an international level, the effects of continued debris growth may make future space activities more dangerous. The next 10 years are pivotal for the future of debris growth and control treaties and regulations.

Informal discussions among technical representatives of the European Space Agency, France, Germany, Japan, and the United States, have already proven to be useful in developing technical policies and practices for controlling orbital debris. Discussions with the Soviet Union have begun and may prove fruitful in the future.

Misconception 6. The danger of satellite collision is greater in GEO than in LEO.

***On the contrary,* the current collision hazard in GEO is estimated to be hundreds of times less than in LEO.**

[1] Nicholas L. Johnson and D. Nauer, History *of On-Orbit Satellite Fragmentations*, 4th ed. (Colorado Springs, CO: Teledyne Brown Engineering, January 1990), NASA Contract NAS 9-18209.

[2] Ibid.

Continued on next page

The probability of collision between a satellite and the debris population is a function of:

- the spatial density of objects in space;
- the relative velocity between debris and a satellite;
- the effective cross-section of the satellite; and
- the duration of the satellite on orbit.

The estimated probability of collision is a factor of 100 to 10,000 less in the GEO band than in LEO because there are fewer objects in the former and they would cross paths at lower relative velocities. Further, because relative velocities are lower, the consequences of a collision are significantly less. However, even though the hazard to satellites in GEO is much less than it is today in LEO, there are concerns for the future. For one thing, we have less data about potential GEO hazards. GEO likely contains other orbiting objects too small to be tracked by current methods (less than about 1 meter at GEO altitude), which could increase the hazard. In addition, more satellites are being launched into GEO and there is no natural cleansing effect such as atmospheric drag to control debris growth in these orbits. A series of satellite breakup events (i.e., a chain reaction) could have catastrophic effects on the GEO satellite population.

Misconception 6. The Soviet Union, which has been responsible for more than 70 percent of all space launches and satellite breakups during the past 25 years, has historically been the source for the majority of Earth's debris population.

***On the contrary,* the United States and the Soviet Union are about equally responsible for the present cataloged population.**

Up until the mid-1980s, the United States was responsible for a larger percentage of debris in orbit. The debris produced by Soviet breakups is usually shortlived since it has historically been produced at lower altitudes. Thus even though the Soviets have produced more debris over time, at present they have less in orbit than the United States (figure 5), but more cataloged objects as a result of a larger number of inactive payloads and rocket bodies.

The rate at which Soviet satellites fragment has actually been increasing while the cataloged population has been decreasing Since 1961 the number of non-Soviet satellite breakups has consistently averaged less than one per year. The Soviet breakup rate has increased steadily from one per year in the 1960s to four per year in the 1980s. However, recently, the Soviet Union has fragmented its satellites in very low orbits, where the resulting debris falls back into the atmosphere relatively quickly.

Misconception 7. Debris from weapons tests in space is a major component of Earth's satellite population.

***On the contrary,* the 12 breakup events associated with space weapons tests are responsible for less than *7* percent of the cataloged population.**

Despite the attention given to weapons tests in space, they have contributed very little to cataloged debris, in large part because they have decayed from orbit relatively quickly. However, such tests may have added smaller debris that cannot be detected with existing methods. Weapons tests could contribute substantially to the debris environment if they were carried out in higher orbits where the effects of atmospheric drag are extremely small.

Misconception 8. Bumper shielding can easily protect a space system from the debris environment.

***On the contrary,* a bumper system can protect a satellite from only a portion of the debris environment.**

Although bumper shielding can protect a spacecraft from impact by some classes of objects, this shielding must be "tuned" to specific types and velocities of debris threats. Hence it will only partially protect satellites. One that would be effective for all sizes and velocities would be prohibitively costly in weight, complexity, and cost. Additional research will be required to protect spacecraft from the most likely collision events. However, shielding will not provide absolute protection. Debris minimization by all parties will also be required to reduce the hazard to acceptable levels. For some large systems, collision avoidance may be necessary.

Misconception 9. People are likely to be killed by fragments of reentering debris.

***On the contrary,* the chances of being struck by debris fragments are extremely small.**

Thousands of debris fragments of all sizes reenter the atmosphere each year. Most disintegrate in the atmosphere and are converted to gases and ash, or breakup into extremely small pieces. Very few actually reach Earth's surface intact. The chances of harm from reentering space debris is much smaller than the chances of being hit by one of the 500 or so meteorites that strike Earth each year. Nevertheless, the uncertainty associated with our inability to predict precisely, in advance,[3] when large objects such as the U.S. Skylab or Soviet Cosmos spacecraft will enter the atmosphere and where they may fall to Earth, coupled with considerable press attention, has led to unwarranted public alarm.

SOURCE: Darren S. McKnight, 1990.

[3]The closer in time an object is to enteringthe atmosphere the more precisely can its entry be predicted by the Space Surveillance Network.